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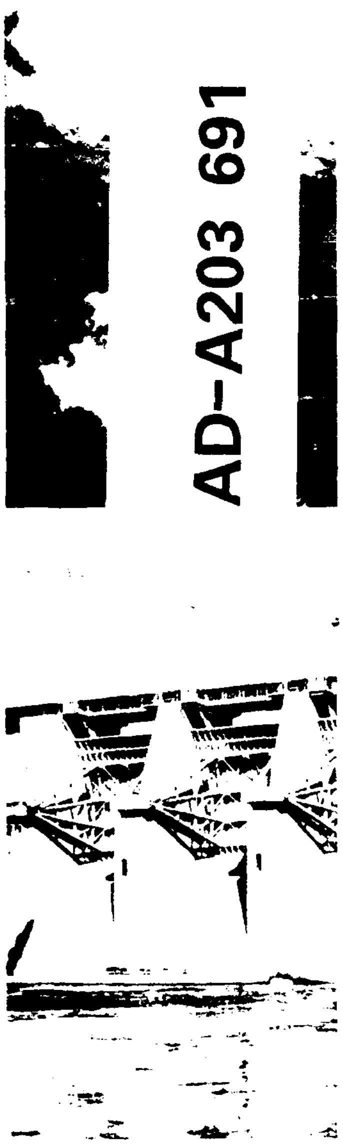

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INVESTIGATION OF ENVIRONMENTAL PROBLEMS IN THE BIG EAU PLEINE RESERVOIR, WISCONSIN

by

Douglas Gunnison, John W. Barko

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

December 1988

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for US Army Engineer District, St. Paul
St. Paul, Minnesota 55101-1479

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Miscellaneous Paper EL-88-18	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Environmental Laboratory 6b. OFFICE SYMBOL *(If applicable)*	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS *(City, State, and ZIP Code)* PO Box 631 Vicksburg, MS 39181-0631	7b. ADDRESS *(City, State, and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAED, St. Paul 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)* St. Paul, MN 55101-1479	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
Investigation of Environmental Problems in the Big Eau Pleine Reservoir, Wisconsin

12. PERSONAL AUTHOR(S)
Gunnison, Douglas; Barko, John W.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
Final report	FROM ______ TO ______	December 1988	38

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUB-GROUP	See reverse.

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

A study of environmental problems in the Big Eau Pleine Reservoir, Wisconsin, was undertaken in response to a request from the Wisconsin Department of Natural Resources to the US Army Engineer District, St. Paul, for planning assistance. The Big Eau Pleine Reservoir has had a history of winter fish kills and summer algal blooms since its construction in 1937 by the Wisconsin Valley Improvement Company. The US Army Engineer Waterways Experiment Station (WES) was asked to examine the results of previous studies and recommendations for water quality improvement and, if appropriate, to provide new recommendations.

The WES scientists reviewed theses written by graduate students at the University of Wisconsin-Stevens Point, who had conducted research on the Big Eau Pleine Reservoir. The WES also examined existing data on dissolved oxygen, biochemical oxygen demand (BOD), and total and orthophosphate phosphorus. The FLUX interactive program for estimating loadings and mass discharges was applied to compute and compare BOD and total and orthophosphate phosphorus loadings in reservoir inflows and releases.

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE *(Include Area Code)* / 22c. OFFICE SYMBOL

18. SUBJECT TERMS (Continued).

Algal bloom
Ammonium-nitrogen
Biochemical oxygen demand
Dissolved oxygen depletion
Fish kill
Orthophosphate phosphorus
Oxygen sag
Reservoir
Sediment oxygen demand
Total phosphorus

19. ABSTRACT (Continued).

Sediment cores were taken by WES personnel from a downstream area near the dam and in an upstream area where inflows are believed to deposit materials during spring runoff. Interstitial water samples from the cores were analyzed for a variety of chemical constituents.

Results of the study indicated that the reservoir is a sink for total phosphorus but releases organic matter in the form of BOD. It was not possible to determine the degradability of organic matter deposited in the upstream delta or to ascertain how much of the reservoir phytoplankton production leaves the system or is degraded in the water column. Additional information on sediment transport, sedimentation rate, and sediment chemistry is required to fully understand the dynamics of sediment-water interactions in the reservoir. Further work is needed to comprehend the relationship between oxygen sags and chemical species released in the water column and to evaluate the effectiveness of an aerator installed in 1980. The WES scientists suggested several potential management alternatives and made recommendations for additional studies to provide the information needed to select the most suitable alternative(s).

Preface

This study was conducted in response to a request from the Wisconsin Department of Natural Resources to the US Army Engineer District (USAED), St. Paul, for planning assistance under Section 22 of the Water Resources Development Act of 1974 (Public Law 93-251). The USAED, St. Paul, particularly Mr. Daniel Wilcox, cooperated in developing this effort. The work was authorized by Intra-Army Order No. 1-001496, 7 June 1988. The research was conducted during the period June to August 1988.

The study was conducted and the report was prepared by Drs. Douglas Gunnison and John W. Barko of the Aquatic Processes and Effects Group (APEG), Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). Drs. William D. Taylor and Robert F. Gaugush of the APEG provided reviews of information, and Dr. Gaugush assisted with technical aspects of the FLUX program. Mr. Harry L. Eakin of the APEG assisted in collection of sediment cores and directed the chemical analyses. Ms. Cynthia Price, APEG, ran the FLUX program and prepared the figures, and Ms. Evelyn Henderson, APEG, assisted with figure preparation. Technical reviews of the report were provided by Drs. Thomas L. Hart, Robert F. Gaugush, and James M. Brannon of the APEG; Mr. Wilcox and Mr. Dennis Holme of the USAED, St. Paul; Mr. Robert Martini of the Wisconsin Department of Natural Resources; and Messrs. Robert W. Gall and David M. Coon of the Wisconsin Valley Improvement Company.

This investigation was conducted under the general supervision of Dr. John Harrison, Chief, EL, and Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division, and under the direct supervision of Dr. Thomas L. Hart, Chief, APEG.

COL Dwayne G. Lee, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

Gunnison, Douglas, and Barko, John W. 1988. "Investigation of Environmental Problems in the Big Eau Pleine Reservoir, Wisconsin," Miscellaneous Paper EL-88-18, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Contents

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

INVESTIGATION OF ENVIRONMENTAL PROBLEMS IN THE BIG EAU PLEINE RESERVOIR, WISCONSIN

Introduction

1. The Wisconsin Valley Improvement Company (WVIC) was formed in 1907 to construct reservoirs on the Wisconsin River system to regulate flows in the Wisconsin River. The Big Eau Pleine Reservoir was constructed in 1937 by impounding the Big Eau Pleine River to assist in providing uniform flow in the Wisconsin River. The 2,760-ha reservoir has had a history of winter fish kills (five major kills between 1963 and 1976) and summer algal blooms since its construction (Shaw and Powers, undated). Studies of the reservoir were conducted during the period 1974-79 to evaluate the sources of water quality problems and specify management practices to reduce these problems (Shaw and Powers, undated).

2. The US Army Engineer Waterways Experiment Station (WES) was asked to examine these studies and other available data to assess the previous recommendations for water quality improvement and, if possible, formulate additional recommendations. The primary objective of this study was to assess the contributions of algae and sediment to the biochemical oxygen demand (BOD) and/or other oxygen demands in the water column during reservoir drawdown. In addition, the study examined, in a general way, the effectiveness of the existing aerator with respect to its ability to mitigate conditions of dissolved oxygen (DO) depletion occurring during the winter. This report integrates existing information on environmental problems, suggests potential management alternatives, and provides recommendations with regard to future monitoring of environmental conditions in Eau Pleine Reservoir.

Methods

Analysis of existing data

3. This investigation consisted primarily of an examination of data obtained during previous studies of the Big Eau Pleine Reservoir. Much of what is known about the reservoir is the result of the efforts of graduate students at the University of Wisconsin-Stevens Point, who conducted thesis

research under the direction of Dr. Byron Shaw during the mid-1970s. Dr. Shaw provided copies of theses by Sullivan (1978), Swalby (1979), Hammermeister (1982), and Vennie (1982), which contained data directly or indirectly related to the loss of DO from the Big Eau Pleine Reservoir. Each thesis was reviewed by an individual at the WES having expertise in the area covered by the document. Individuals were asked to assess the work presented and the validity of the conclusions reached.

4. Several other items were provided by the WVIC. These included DO isopleths for the winter months (January through March) of 1974-88 and yearly DO, BOD, total phosphorus, and orthophosphate phosphorus data for the years 1973-88. Inflow data for the reservoir were obtained through WVIC from the US Geological Survey for its Stratford, WI, gauging station on the Big Eau Pleine River. Data on reservoir outflows were supplied by WVIC.

5. In evaluating the DO isopleths supplied by WVIC, the isopleth lines that surrounded water having 2.0 mg/ℓ DO or less were considered regions of low DO, while the lines that surrounded water having 1.0 mg/ℓ DO or less were considered essentially anoxic. Reference lines were drawn from the locations of the isopleth lines along the bottom of the reservoir drawing to the mileage scale on the bottom of each figure; then, the location and extent of bottom length within these lines were determined. This procedure does not indicate the extent to which a pocket of water containing a given level of DO extends into the overlying water column; however, visual inspection of the isopleths indicates that this procedure is a reasonable means for approximating the extent of reservoir length included within low DO-bearing waters.

6. Biochemical oxygen demand, total phosphorus, and orthophosphate phosphorus inflow and outflow data were examined using the FLUX interactive program for estimating loadings and mass discharges passing a tributary or outflow monitoring station (Walker 1987). The purpose of this program is to interpret water quality and flow information derived from intermittent grab or event sampling to provide estimates of mean (or total) loadings over the complete flow record between two dates. The FLUX model was run using the data provided for each year (1975-86). However, the fact that most of the total phosphorus and BOD samples were taken at times when flows were considerably below their maximum levels meant that this program could be successfully applied to only two or three of the years. Orthophosphate phosphorus data were even more difficult to analyze because of the limited number of samples

taken in each of the years examined. To circumvent this, BOD, total phosphorus, and orthophosphate phosphorus data were each pooled over the entire period (1975-86) to increase the number of available samples. The FLUX program then used the pooled samples in conjunction with flows for each year to make the loading calculations. This type of data manipulation works well when there is a good relationship between loading and flow, and appropriate computations were done to establish the validity of this relationship. The significance of the differences between inflows and outflows was established using a two-tailed t-test (Zar 1974).

Chemical analysis of reservoir sediment

7. Sediment cores were taken on July 27, 1988, and studied to assess the potential for releases of reduced iron, ammonium-nitrogen, and dissolved organic carbon from the sediment. Mr. David Coon of WVIC kindly assisted in this effort by supplying a boat, and Ms. Cathy Wendt of WVIC piloted the boat and assisted in site location. The locations selected for core sampling were as follows. The upstream site was located approximately 12 miles* upstream of the dam on the south side of the Big Eau Pleine Reservoir. Water in this location was approximately 4 ft deep at the time of sampling. This site is in the general vicinity where inflows are believed to deposit a delta of material from spring runoff in the watershed of the Big Eau Pleine River and where the DO sag is thought to form. The delta is a likely source of resuspended sediment resulting from ice scour during winter drawdown. The downstream site was located off the south side of the main channel approximately 2 miles from the dam at a neck in the lower reservoir. Water in this location was approximately 15 ft deep at the time of sampling. This site is in a probable location for deposition of scoured sediment.

8. Three cores were taken from each site with a 2-in. Wildco (Wildco Instruments, Inc., Saginaw, MI) sampler. To preserve the anaerobic integrity of the samples and prevent mixing of sediment during shipment, core samples were treated as follows. Upon retrieval, the plastic sleeve was removed from the corer, and the top of the sleeve was covered with a cap having a small hole to permit extrusion of water. The bottom of the core sample was pushed upward in the sleeve using a core extrusion piston until the top of the

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

sediment core sample reached the top of the sleeve. The cap with the hole was then replaced with a solid cap. The core was measured from the top to a total length of 15 cm, and the sleeve and core were cut at this point with a hacksaw. The freshly cut core and sleeve bottom was also covered with a solid cap. Cores in their sleeves were stored on ice and brought back to the WES where the first 10 cm of each core was extruded under nitrogen. Solids from each site were composited and then separated from the interstitial water by high-speed centrifugation at 4° C (Barko and Smart 1986). Interstitial water samples were acidified with hydrogen sulfate and stored at 4° C until analyzed for orthophosphate phosphorus, ammonium-nitrogen, dissolved inorganic carbon, dissolved organic carbon, reduced iron and manganese, calcium, potassium, and sodium using the methods of Barko and Smart (1986). Sediment solids were analyzed for moisture content, bulk density, organic content, and texture following the procedures of Barko and Smart (1986).

Results and Discussion

Dissolved oxygen levels

9. Using the methods described above, it was possible to delineate changes in location and extent of parcels of low DO (2.0 mg/ℓ or less DO) and essentially anoxic (1.0 mg/ℓ or less DO) waters in the Big Eau Pleine Reservoir (Figure 1). Based on the individual graphs in this figure, movement of water containing low DO levels down the length of the reservoir was most apparent in 1974 and 1975 and somewhat less apparent in 1976, 1981, and 1982. Using the WES criteria, it was not possible to confirm or deny a similar movement of low DO water downstream for the remaining years. Since it was difficult to see the movement of the DO sag (an area of concentrated DO depletion) during most years and because WVIC uses the movement of the DO sag (based on other criteria) to determine when to turn on the aerator, WES asked WVIC to explain their criteria and pinpoint the location and movement of the sag on each isopleth. The locations of the DO sags supplied by WVIC were then superimposed upon the locations of low DO and essentially anoxic water determined by WES methods. This information is presented in Figure 2. In responding to WES' request for information on DO sag location and movement, the WVIC also provided an analysis of its own winter DO monitoring data for 1974-88. This analysis is summarized in Table 1.

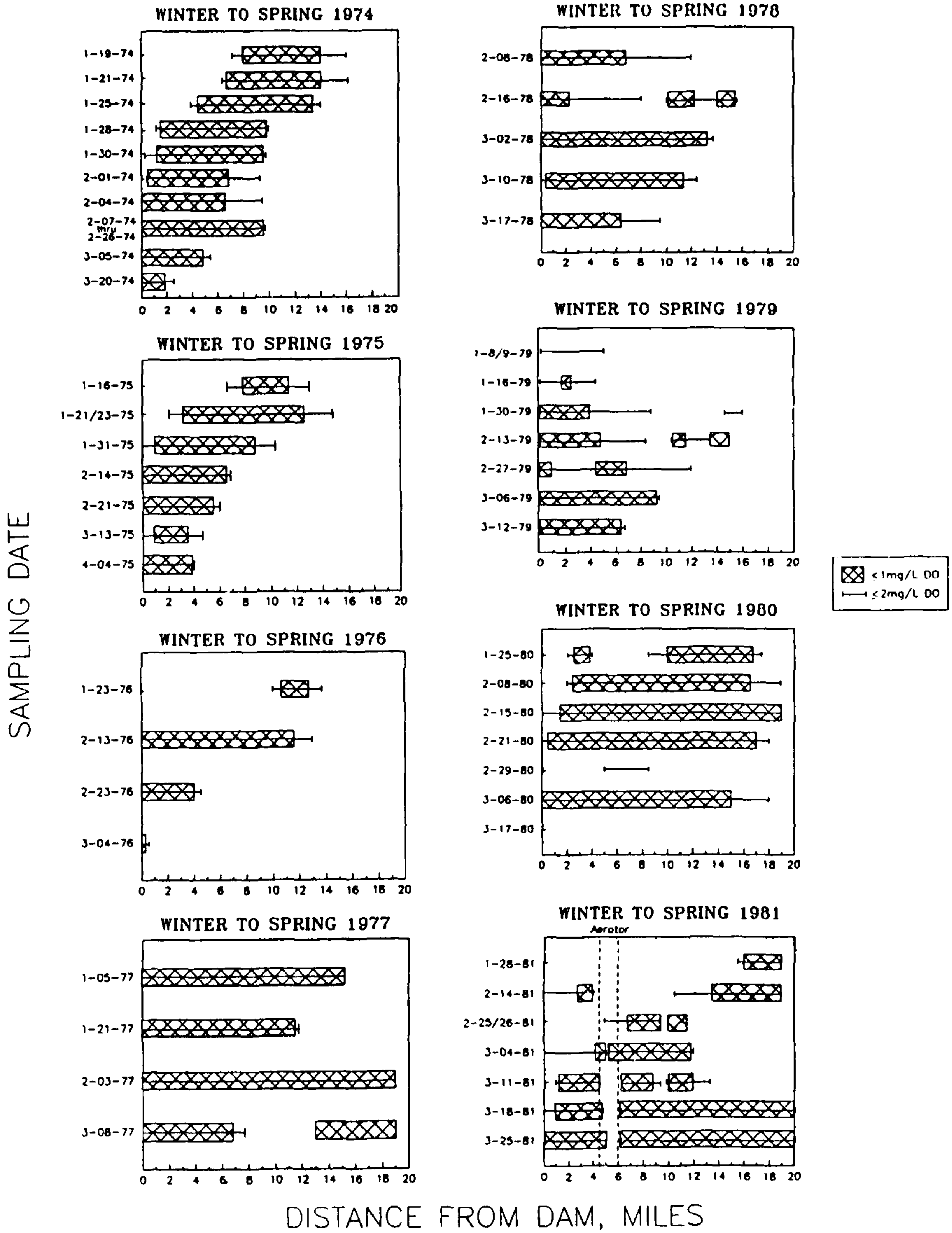

Figure 1. Dissolved oxygen levels (≤1 and ≤2 mg/ℓ DO) along bottom of Big Eau Pleine Reservoir, as determined by WES (Continued)

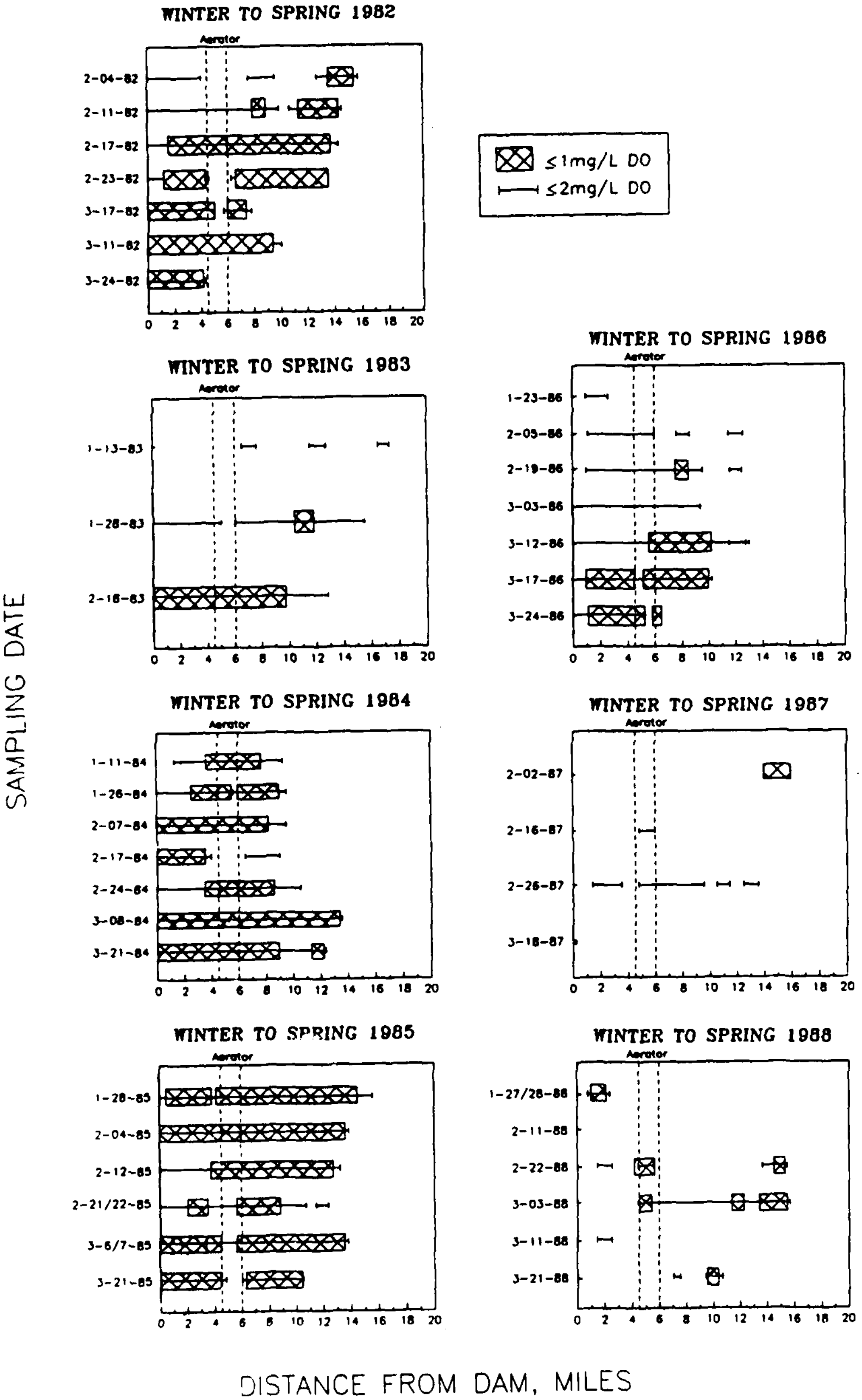

Figure 1. (Concluded)

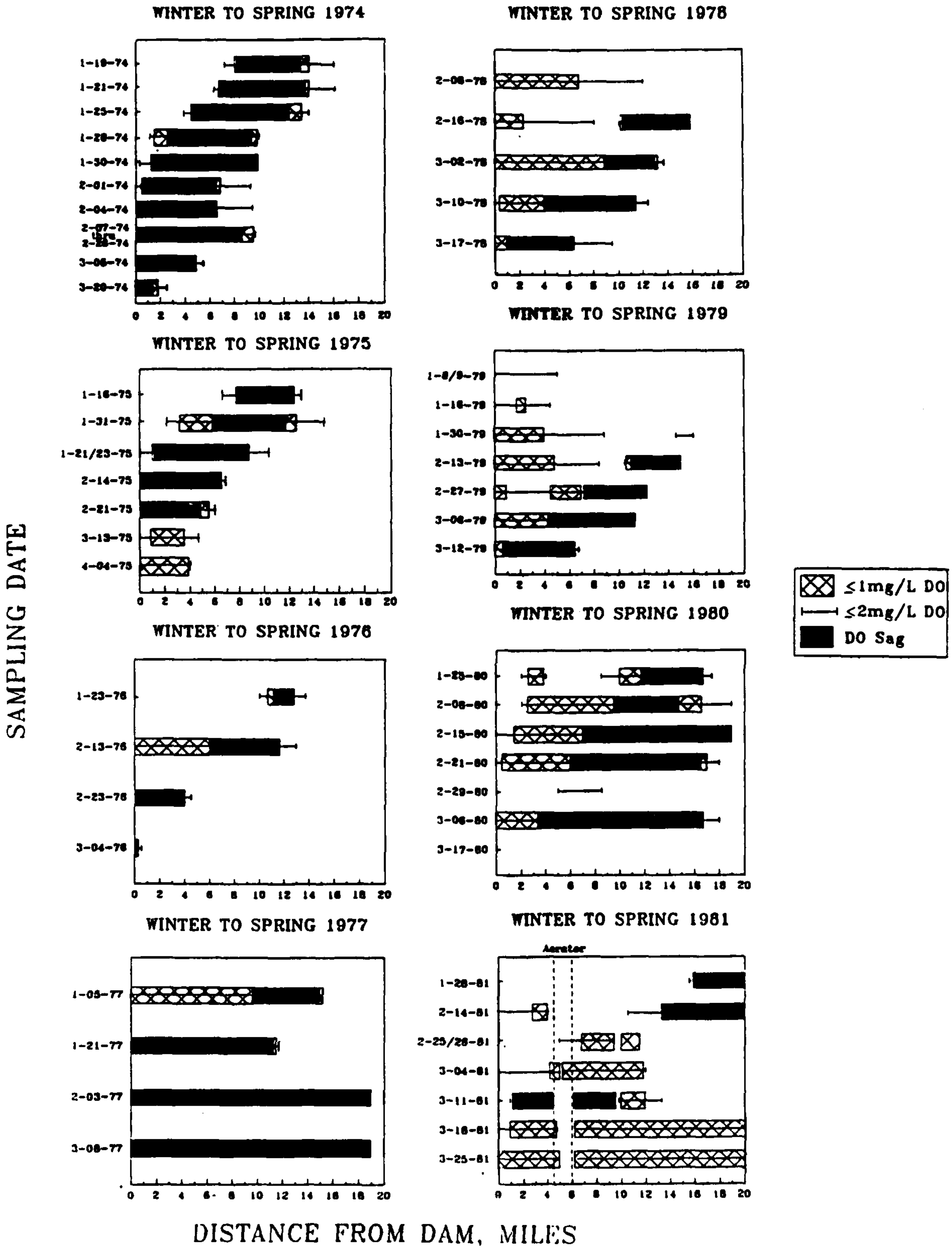

Figure 2. Dissolved oxygen levels (≤1 and ≤2 mg/ℓ DO) along bottom of Big Eau Pleine Reservoir (location of DO sag is superimposed) (Continued)

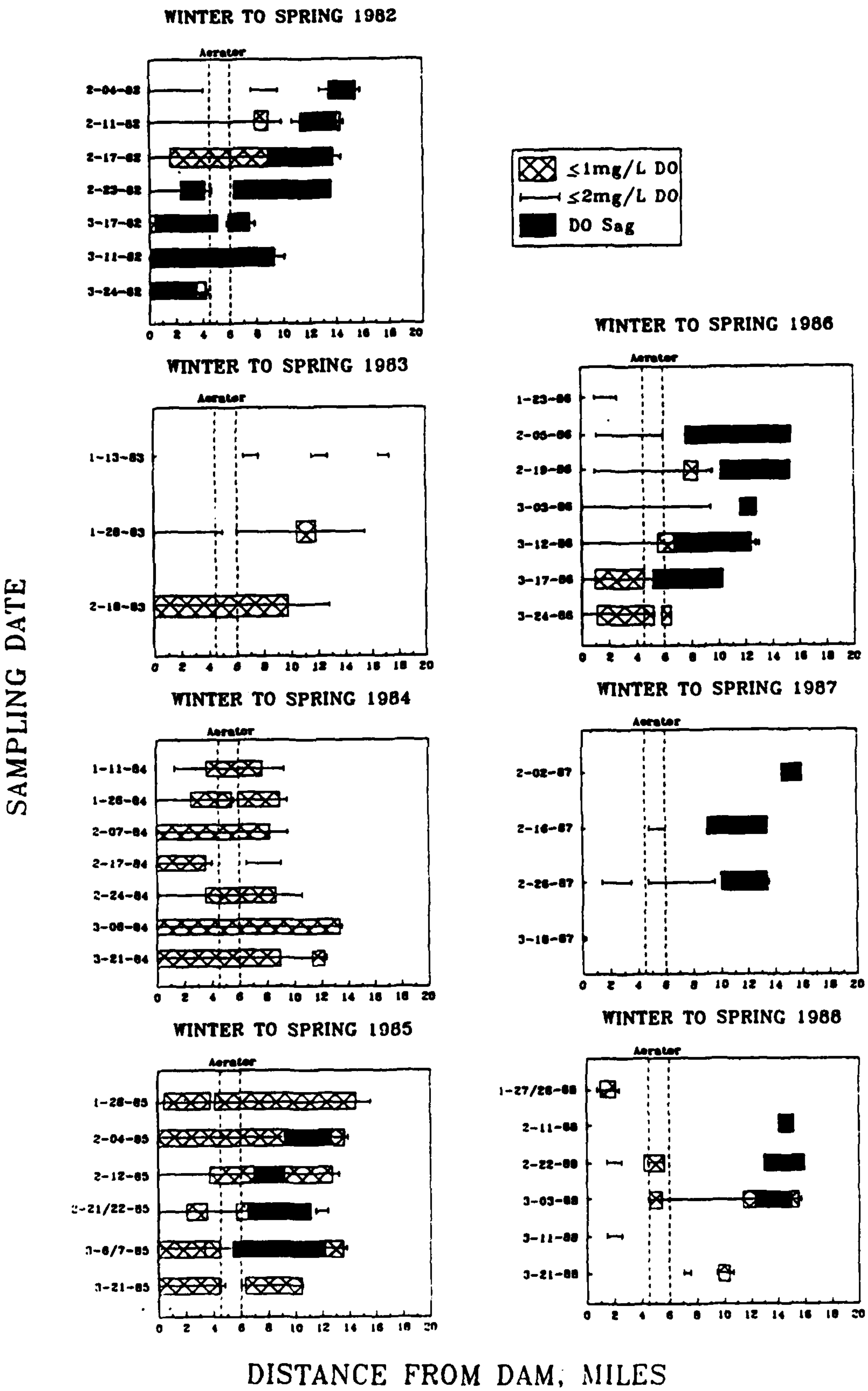

Figure 2. (Concluded)

10. In comparing the WES results (Figure 1) with the information provided by WVIC (Figure 2), it is important to understand WVIC's approach to locating areas of DO sag and hypolimnetic oxygen demand. According to WVIC, the DO sag initially develops in parts of the reservoir where decreased DO levels reach from the sediment upward to the base of the ice layer; decreased DO levels throughout the water column are not necessarily as low as 1 to 2 mg/ℓ. The sag initially appears as a simple hypolimnetic demand, but eventually expands into a "swelling" that moves up to the underside of the ice followed by an "expansion" downstream. The DO sag does not always lower DO levels to 0; however, the sag does involve a substantial reduction in DO levels (the example given was from 10 to 4 mg/ℓ). The WVIC further noted that the DO sag does not normally develop until the reservoir water level drops to elevation 1,135 ft or less. At this level, the reservoir width and depth at river miles 12.0 to 17.0 are constricted to approximately the area of the old river channel, resulting in increased current with subsequent sediment scouring and resuspension of upstream deposits (WVIC opinion). (Note the possibility that resuspension may not occur during winter low flow, but ice scour and shelving may disturb sediments during this time.) The sag moves downstream with drawdown and further constriction of reservoir width and volume. Other phenomena, particularly sedimentation and precipitation events in the preceding year coupled with the nature and extent of drawdown, appear to influence the development and movement of the sag. Support for this description is basically substantiated by the information supplied by WVIC (Table 1) and to some extent by the data shown in Figure 2.

11. In contrast, WES looked at stretches of low DO and essentially anoxic water only in bottom waters. In most cases, this approach yielded somewhat greater expanses of low DO coverage than those indicated by WVIC. Occasionally, the span occupied by the DO sag bridged separate areas of low-DO/nearly anaerobic water (see isopleths for 3-08-77, 2-13-79, 2-05-86, and 3-03-88 in Figures 1 and 2). The WES approach indicates that while the DO sag appears to develop upstream, a hypolimnetic demand often develops nearer the dam as well, sometimes expanding upstream (compare Figures 1 and 2 for 1978, 1979, 1980, 1982, 1985, 1986). As the upstream sag moves downstream, the sag and the hypolimnetic demand near the dam appear to converge, forming a large expanse of low-DO water encompassing extensive lengths of the reservoir bottom

(in Figures 1 and 2, compare 2-16-78 and 3-02-78; 2-13-79 through 3-12-79; 1-28-81 through 3-11-81; and 2-04-82 through 3-11-82).

12. The location of the section of the reservoir influenced by the aeration system is also shown in Figures 1 and 2, starting in winter-spring 1981 and in all the years thereafter. The aeration system was installed in 1980 and was first used in winter 1981. The aerator is used only in winter, normally from the end of February until ice-out (usually mid- to late-March).* An effect on DO levels, possibly attributable to the aerator, occurred in the general location of the aerator during March 1981. Other associations between the aerator and increased DO levels in and around the DO sag were apparent during this and later years; however, the aerator does not always appear to be effective in breaking up areas of low DO water.

Biochemical oxygen demand (BOD)

13. Thesis information. Swalby (1979) provides a general description of the changes in BOD concentrations occurring in the Eau Pleine Reservoir system. It is clear that the highest BOD values were attained during the summer months, and most of the BOD was exerted in response to algal blooms (the system was very productive) and their ensuing decomposition. Swalby's work indicates that in the reservoir, filterable BOD (passing a No. 300 soil sieve that retains particles in excess of 50 μ) comprised most of the total BOD throughout the year (84 percent), while nitrogenous BOD constituted 31 percent of the total BOD. In the inflows, filterable BOD made up 87 percent of the total BOD, while nitrogenous BOD again comprised 31 percent of the total BOD. This indicated that most of the BOD, both in the inflows and in the reservoir itself, was in dissolved or fine particulate form (50 μ or less), and nitrogenous BOD made up a substantial portion of the total BOD. Swalby also indicates that BOD alone was not sufficient to explain the extremely low DO conditions in the reservoir during the winter, although it is clear that BOD did contribute to these low levels.

14. Swalby made a good case for the interplay of several factors in causing the observed DO depletion during the winter months. Dissolved oxygen levels in inflows remained relatively high during the winter (6 mg/ℓ). Also, BOD entering the reservoir was low, suggesting that factors within the

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* Personal Communication, 1988, Mr. David M. Coon, Wisconsin Valley Improvement Company, Wausau, WI.

reservoir itself, rather than factors in the inflows, were responsible for much of the downstream depletion. The exact role of sediment oxygen demand in oxygen depletion during the winter is not clear, based on our review of Hammermeister's (1982) work (see paragraphs 27-28).

15. Swalby's analysis indicates that during the summer months, the BOD in the water immediately overlying the sediment surface ("bot" in Table 2) was roughly half of the BOD present in the upper surface layer of water ("top" in Table 2) of the reservoir; however, the mean BOD values for these locations were not significantly different from each other. The BOD values for both of these locations appear to have exceeded BOD levels in water from the river (inflow), but because of the lack of replication in river water samples, it is not possible to determine if these differences were significant. During the fall, surface and bottom water BOD levels were nearly equal and, again, there was no significant difference between these values. The BOD levels in the inflows were significantly lower than values in either the surface or bottom waters. In the winter, the bottom waters appeared to have larger BOD levels than the surface waters; however, because only one sample was used, the reality of this distribution of BOD is uncertain. In addition, there was no significant difference between BOD levels in the inflow and levels in the surface water and perhaps also the bottom water. The distributions of BOD between the top and bottom of the reservoir appear nearly equal in the spring; but again, only one sample was used for the bottom water. There was also no significant difference between inflow BOD samples and the other two samples. The reservoir is polymictic when not under ice cover, and it is likely that the BOD levels during the spring, summer, and fall months were nearly the same at all depths.

16. According to Swalby (1979), the BOD composition of reservoir waters was very similar during the spring and fall seasons, both seasons showing comparable concentrations of biomass and detritus in the BOD samples. In both seasons, the detrital portion of the solids in the BOD sample was approximately four times the level of the biomass fraction. During the fall, BOD from the bottom water was directly correlated with the detrital fraction. These observations indicated that reservoir BOD during spring and fall may have been principally detrital in nature, resulting from detrital fractions entering with spring runoff, fall rains, stream scouring, and/or biomass decomposition. Surface water BODs during winter were correlated with biomass

and detritus, but little biomass was present in the samples. Bottom BOD samples during summer were strongly correlated with biomass but were negatively related to large particulate BOD and detritus; this suggests that bottom samples were composed of dissolved organic matter or very small algal cells. This information indicates that the substances contributing to BOD in the system undergo seasonal changes in composition. (The WVIC notes that Swalby may have missed the spring refill during his sampling. The Big Eau Pleine Reservoir is a very flashy system, and spring refill may occur in a 2- to 3-day period. During this time, a high percentage of the external BOD may enter the system and be deposited in the upper reaches of the reservoir.)

17. Results of the FLUX program. Table 3 presents BOD fluxes in water moving into and out of Eau Pleine Reservoir as estimated by the FLUX program. For all but 2 of the 14 years examined, estimated loss of BOD in outflows from the reservoir exceeded imports to the reservoir from the Big Eau Pleine River. It is important to note that the inflow information is based solely on limited data for the Big Eau Pleine River; this river accounts for the bulk of the inflow to the reservoir (approximately 84 percent). Freeman and Fenwood Creeks contribute the remaining 16 percent of the inflows. Since Freeman Creek is a class 2 trout stream,* it is likely that this tributary contains high levels of DO and the levels of BOD are probably low. Since the flows from Freeman and Fenwood Creeks are not gauged, it is not possible to model these inflows. However, it is likely that inclusion of these relatively minor inflows would not appreciably change results regarding BOD flux, based on the Big Eau Pleine River analysis alone.

18. The reservoir itself is highly productive (see the following section), and autochthonous production undoubtedly contributes substantial quantities of BOD to the reservoir. Moreover, BOD levels in the reservoir can be high. For example, visual inspection of BOD levels for the reservoir supplied by WVIC indicates occasional values well in excess of 30 mg/ℓ at the aerator. These levels exceed maximum values for both inflows and outflows and are much higher than the range of values specified by Swalby (1979). In addition, BOD is a very labile constituent. The 3-month retention time of water in the reservoir makes it very doubtful that the BOD entering the reservoir and

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* Personal Communication, 1988, Mr. David M. Coon, op. cit.

remaining in the water column during the spring, summer, and fall months survives long enough to leave in the outflows.

19. It is important to note that the FLUX program deals only with BOD in the water column. Neither the FLUX program nor any of the data WES received provide information on the long-term fate of BOD potentially deposited during spring runoff. The FLUX program accounts for materials entering and leaving the reservoir with water on a yearly basis. Since results of the FLUX program showed greater annual BOD losses than gains by the system, some form of BOD appears to be generated within the project. Based on this information, much of the BOD leaving the project is probably generated within the reservoir.

Nutrient loading, primary production, and decomposition

20. The principal objective in examining the nutrient data was to determine possible relationships between algal blooms and phosphorus loadings. Phosphorus loadings were a concern expressed in the original request from the State of Wisconsin to the US Army Engineer District, St. Paul. Sullivan's (1978) work (see below) indicates the summer biomass is dominated by blue-green algae capable of nitrogen fixation. Thus, WES did not examine nitrogen loadings to the reservoir in the present study.

21. Thesis information. Based on Vennie's (1982) report, the reservoir is both polymictic and eutrophic. The agricultural watershed apparently contributes 97 percent of the annual phosphorus load to the reservoir; 54 percent of the phosphorus is imported during the spring runoff period. Sixty-two percent of the annual nitrogen loading to the reservoir is also contributed by the agricultural watershed during the spring runoff period. The internal reservoir biology and chemistry are influenced by the changing water level of up to 9 m annually.

22. It is apparent from Sullivan's (1978) work that *Aphanizomenon* dominates the summer biomass and that phosphorus loading during drawdown in the summer months is largely internal. While the reservoir is subject to nearly continuous wind mixing, we would still expect intense microbial activity, fueled by the degradation of organic matter, to produce anaerobic conditions at or near the sediment surface in the summer. With a high nutrient gradient (phosphorus) at the sediment-water interface and a lake volume decreasing to low levels, conditions are optimal for increasing lake phosphorus levels.

This system is potentially worsened by physical transport of nutrients from the sediment into the water column due to turbulent mixing.

23. Results of the FLUX program. The results of the FLUX program for total phosphorus are presented in Table 4. While the total phosphorus flux into and out of the Eau Pleine Reservoir varied in magnitude from year to year, the total phosphorus flux into the reservoir exceeded the flux out of the reservoir nearly every year. The only exception was 1985 when there was no significant difference between fluxes into and out of the system. Table 5 presents results of the FLUX program for orthophosphate phosphorus. The entire data set contained only 99 samples for the inflow and 45 samples for the outflow over the period 1975-86. Using the pooled data, the FLUX program was able to perform inflow and outflow loading calculations for each of the 12 years included in the data set. In every year examined, orthophosphate phosphorus flux into the project significantly exceeded losses in outflows. Based on these computations, the reservoir appears to be accumulating large levels of total and orthophosphate phosphorus each year. As was the case for the BOD information, the Freeman and Fenwood Creek tributaries are not gauged, and the contributions of the inflows from these streams cannot be estimated. Retention in the reservoir already exceeds losses from the reservoir; thus, additional accounting for loadings of phosphorus from the two minor tributaries would perhaps exaggerate this trend.

24. Computations were made of DO demand exerted through decomposition of algae, based on average rates of productivity for 1975 and 1976. For this calculation, Sullivan's (1978) annual productivity estimates of 300 g C/m^2 in 1975 and 605 g C/m^2 in 1976 were used; these figures are lower than those computed based on average rates of C^{14} productivity (474 g C/m^2 in 1975 and 1,022 g C/m^2 in 1976). The computations are as follows:

a. Assuming all carbon is converted to CO_2 during decomposition of algae, and using the oxygen consumption value of 32 g O_2/12 g C = 2.67 g O_2/g C, the required O_2/m^2 range is 2.67 × 300 to 2.67 × 605, or 801 to 1,615. Dividing this by 365, a range of 2.19 to 4.42 g O_2/m^2/day is obtained. This is for the entire water column. It is not really possible to determine how much of this is exerted at the sediment surface. Obviously, if the demand were to remain constant throughout the year, the impact would be much more severe during the winter months. At this time, since there is less water and the ice cover prevents reaeration, a lower total supply of DO is present in the water column.

b. Assuming the mean depth for the reservoir is 4.8 m (see any of the above theses), the volume of water underlying 1 m^2 is 4.8 m^3. The oxygen consumption range given in a above thus occurs in a water column of 4.8 m^3 of water or

$$\frac{2.19 \text{ g } O_2/\text{day}}{4.8 \text{ m}^3} = 0.456 \text{ g/m}^3/\text{day}$$

$$\frac{4.42 \text{ g } O_2/\text{day}}{4.8 \text{ m}^3} = 0.921 \text{ g/m}^3/\text{day}$$

c. Since there are 1,000 ℓ in a cubic metre, each of these consumption values is be divided by 1,000 to express consumption in grams/litre/day. Following this, the resultant values are converted to milligrams (multiply value in grams by 1,000). This, of course, does not change the value of the numbers obtained in step b:

$$0.456 \times 10^{-3} \text{ g/ℓ/day} \times 10^3 \text{ mg/g} = 0.456 \text{ mg/ℓ/day}$$

and

$$0.921 \times 10^{-3} \text{ g/ℓ/day} \times 10^3 \text{ mg/g} = 0.921 \text{ mg/ℓ/day}$$

d. To enable comparison of these values to Swalby's (1979) BOD numbers, each of these consumption values is multiplied by 5 and 20 days:

For 1975: Oxygen consumed in 5 days = 2.3 mg/ℓ
Oxygen consumed in 20 days = 9.2 mg/ℓ

For 1976: Oxygen consumed in 5 days = 4.6 mg/ℓ
Oxygen consumed in 20 days = 18.4 mg/ℓ

e. Probably not all of the algal carbon will be converted to CO_2. However, this computation also does not consider the nitrogenous BOD that will have been expressed in 20 days. In addition, these computations assume constant kinetics over the course of a year.

25. Based on the above estimates, oxygen consumption resulting from degradation of primary production will have 5-day BOD values in the range of

2.3 to 4.6 mg/ℓ and 20-day BOD values of 9.2 to 18.4 mg/ℓ. Swalby's BOD estimates had a similar range (1.1 to 6.5 mg/ℓ for 5 days to 2.7 to 16.6 mg/ℓ at 20 days). However, this information does not agree with some of the maximum values for BOD observed in the reservoir.

26. A basic problem in the overall analysis is that we do not know how much of the autochthonous algal production (and associated detrital matter) is washed from the system and how much is deposited in the sediment. In addition, it is not known how much of the BOD in the reservoir and reservoir releases is derived from upstream organic inputs and how much is derived from autochthonous algal production. The summer algal production alone is more than ample to cause most of the winter oxygen depletion, if the biomass does not leave the system. The productivity is high enough to supply degradable organic matter capable of depleting DO, even if the water volume were not reduced during the winter. This is worsened by the drastic reduction in both water volume and DO mass during many winter seasons. Decomposing algae in the sediments appear to explain the winter hypolimnetic oxygen demand observed in the area of the dam.

Sediment oxygen demand

27. Thesis information. Hammermeister (1982) gives seasonal sediment oxygen demand (SOD) values for sediment cores taken from the Big Eau Pleine Reservoir (Table 6). According to his information, SOD at 20° C varies from a low of 0.56 g O_2/m^2/day in the summer to a high of 0.83 g O_2/m^2/day in the fall. However, because of the large standard deviations, there is no significant difference between seasons. For this reason, the yearly average of 0.15 g O_2/m^2/day at 4° C is probably the best available estimate for SOD exerted during the winter months. This value is for the surface of stable sediment only and does not include any possible changes in SOD that may occur when scour increases the total surface area of sediment exposed to oxygen-bearing water. However, an SOD of 0.15 g O_2/m^2/day at 4° C seems moderate or even mild for a reservoir demonstrating the productivity of the Big Eau Pleine Reservoir.

28. Hammermeister (1982) emphasized the biological aspects of SOD. He made an effort to estimate abiological SOD resulting from oxidation of reduced chemical species by poisoning the sediment to eliminate the biological component. He also measured levels of iron, manganese, exchangeable ammonium, organic matter, and available phosphorus in dried sediment samples, but not in

the sediment interstitial water. For this reason, Hammermeister's measurements cannot be used as a means to determine the potential for soluble reduced species, such as Fe^{+2} and Mn^{+2}, to diffuse from sediment interstitial water into the overlying water column.

29. Chemical analysis of reservoir sediment. Values for the parameters examined in the interstitial water and the bulk chemical properties for sediments from the upstream and downstream sites of the Big Eau Pleine Reservoir are presented in Table 7. With the exception of soluble reactive phosphorus (SRP) and dissolved organic and inorganic carbon levels, interstitial water values from the two locations were generally quite close. In fact, the similarities between the sediments and their interstitial water contents are remarkable in view of the 10-mile distance separating the two sites.

30. The dissolved iron and manganese levels from both locations were similar to levels obtained in pore waters of Eau Galle Lake, a Corps of Engineers impoundment in west-central Wisconsin (21.9 and 8.5 mg/ℓ for iron and manganese, respectively) (see Brannon, Chen, and Gunnison 1985). While reduced iron and manganese values were not as high as those observed in some impoundments, they were at levels that have the potential to contribute significant concentrations of these elements to the water column through diffusion under anoxic conditions or during sediment disturbance. It is not possible to determine the amount of these metals that enters the water column from sediment core data. Sulfide was not measured in this study, so it is not known if iron sulfide has the potential to form in significant levels in the water column. However, none of the core samples had a distinctive sulfide odor.

31. Ammonium values for sediment interstitial waters did not display unusual levels or major differences between sites. Interstitial water SRP values were of interest. The upstream site contained over 5.5 times more SRP than the downstream site. This observation is particularly interesting in view of the indications from the FLUX program that the reservoir tends to accumulate phosphorus and the belief that deposition of sediments containing high levels of SRP occurs in the upstream site during the spring months. The occurrence of higher levels of SRP in the summer months in the upstream sediments is in accordance with this scenario.

32. Bulk sediment and interstitial water organic matter and dissolved carbon contents provided some interesting observations. Downstream bulk

sediment organic matter levels were higher than upstream levels, but the difference is of questionable significance (difference = 1.45 percent). In like manner, interstitial water levels of dissolved inorganic and organic carbon in upstream sediment cores were not that different from their downstream counterparts, the differences being 5.1 and 3.2 mg/ℓ for dissolved inorganic and organic carbon, respectively.

33. Sediment moisture and bulk density values indicated that the upstream sediment was denser and had a higher water content than the downstream sediment. Sediment textural properties indicated that the two core sites were quite similar in their composition. The upstream site had a slightly lower sand content, but an elevated level of silt and nearly identical level of clay in comparison to the downstream site. In addition, the downstream core samples had a coarser visual appearance than their upstream counterparts.

34. The Big Eau Pleine Reservoir has the capacity to generate high levels of biologically labile organic matter as a result of intense biological productivity in the water column. (An algal bloom was observed during the sediment core sampling trip. It extended from the upper site to the lower site.) This fact, coupled with the generally shallow depths of this reservoir (mean depth = 4.8 m), makes it extremely likely that at least some portions of the sediment surface will be covered with readily degradable organic matter, particularly during the winter when ice cover precludes mixing of the water column. It was not possible to determine how much of the settled organic matter actually becomes incorporated into the sediment and whether this material settles evenly over the bottom of the reservoir or is concentrated in the old river channel. It is expected that the sediment surface layer will tend to be reduced, rather than oxidized. Consequently, there would be a strong tendency for the sediment to release reduced iron and manganese when overlying waters become anoxic. Reduced iron has a very high immediate oxygen demand that can be exerted, even at low temperatures, and there is a possibility that release of reduced iron, or perhaps iron sulfide, may contribute significantly to winter oxygen demand. It is important to note that reduced iron is extremely labile in the presence of oxygen. It is likely that none of the reduced iron present in any of the samples included in Swalby's BOD study (above) would have survived the initial preincubation aeration used for the BOD test.

Integration of Available Information

35. The Big Eau Pleine Reservoir is a eutrophic system enriched by the upstream agricultural watershed. Much of the enrichment occurs during the spring when snowmelt and spring rains combine to wash material into the system from the watershed. Some of this material load, phosphorus in particular, is deposited in the upper portion of the reservoir (at or above mile 12.0), while the remainder remains in suspension/solution and enters the main body of the reservoir. The reservoir is a sink for total phosphorus, and this nutrient supports high levels of primary productivity, primarily in the form of algae. Organic matter imported with inflows, together with algae produced in the reservoir, provides continued renewal of BOD within the system.

36. Deposition of nutrient- and organic-rich sediment in the upper reaches of the reservoir is accompanied by deposition of phytoplankton in the body of the reservoir. Oxidation of these materials in the sediment promotes development of anaerobic conditions within the sediment. This, in turn, favors accumulation of reduced inorganic substances (iron, manganese, and perhaps also sulfide) and easily degraded organic materials in the sediment. Winter ice scour, induced by decreasing water levels (below elevation 1,135), favors scouring or other mechanisms for suspension and movement of upstream deltaic deposits and their interstitial water into the old river channel. Low inflows coupled with continued drawdown pull the dissolved and suspended materials downstream. Because these materials contain both biologically available organic matter and oxygen-demanding reduced inorganic species, they exert an oxygen demand on the stream, which is manifested as a DO sag. Reduced inorganic species and biologically available organics are also continually released from the anaerobic bottom sediment in the main body of the reservoir. The sediment in this portion of the project is not suspended, and therefore does not have the large surface area of exposure given to the resuspended materials upstream. Nonetheless, the release of these materials in downstream reaches results in hypolimnetic oxygen demands, which form areas of low DO and essentially anoxic water at various locations, particularly near the dam.

37. Oxygen depletion is exacerbated by the low reserve of DO in the overlying water due to the vast decrease in reservoir volume that accompanies drawdown. Some of the downstream hypolimnetic demand pockets become quite extensive in area and may also involve much of the overlying water column. As

the DO sag moves downstream, it joins with the existing pockets of hypolimnetic demand to involve large sections of the reservoir. On occasion, the pocket nearest the dam grows in the upstream direction. The approaching sag may merge with the hypolimnetic pocket near the dam to involve much of the reservoir in low DO or anoxic conditions.

38. Generally, WES was in agreement with WVIC's analysis and explanatory scenario of upstream development of a DO sag followed by movement downstream of this sag in association with decreased inflows and continuous outflows. In addition, WES considered hypolimnetic demands to be quite important in downstream reaches, possibly compounding DO depletion produced by the sag itself. Hypolimnetic demands may also be influential in the reformation of the DO sag downstream of the aerator (area of influence located at and downstream of approximately mile 6). In addition, hypolimnetic demands upstream of the dam may add oxygen-demanding substances to the sag as it moves downstream. However, it was not possible to weigh the relative contributions of each of these mechanisms to the overall low DO problem in the reservoir.

39. Depending on the intensity and extent of low DO conditions, oxygen released from the aerator may or may not promote consumption of all the oxygen-demanding materials in the sag as it moves downstream. In most years, the aerator appears able to raise DO levels in the sag, but lacks the capacity to handle all of the demand. Moreover, hypolimnetic demands downstream of the aerator coupled with any remnants of the DO sag will often tend to diminish added DO despite the presence of the aerator.

40. In summary, the reservoir is a sink for total phosphorus but releases as much or more organic matter (manifested as BOD) as it receives. Therefore, the reservoir serves as a chemostat, generating organic matter. In effect, the reservoir is a generator of reducing power, wherein mixing and sediment resuspension due to drawdown and/or ice scour release the reducing power in a manner analogous to the unloading of voltage by an electrical capacitor. The pathways for electron flow are through the decomposition of organic matter and the oxidation of reduced inorganic substrates. Both of these processes result in significant oxygen depletion from the water column.

Information Deficiencies

41. It was not possible to determine the degradability of the organic matter that is deposited in the upstream delta. Neither could it be determined how much of the phytoplankton production ends up in the sediments, how much leaves the system, and how much is decomposed in the water column. Information on sediment transport, sedimentation rate, and sediment chemistry is required to provide (a) information on materials released from reservoir sediments, (b) long-term sediment accretion rates, and (c) an understanding of the relationship of changes in watershed activities to chemical properties of the sediment.

42. It could not be determined if the demands in the sag and the hypolimnion are occurring from dissolved species released into the water column due to sediment disturbance or from resuspended sediment moving downstream, or both as hypothesized in the preceding section.

43. The information available is insufficient to address aerator effectiveness in depth. Isopleth data show improved DO in the region of the aerator during its operation, but do not routinely demonstrate the presence of improved DO levels in water immediately downstream from the aerator. Apparently, no fish kills have occurred downstream since aerator operation was initiated. For this reason, the aerator might appear to be working. However, the reason cannot be determined, since DO levels downstream of the aerator often reach low levels. Also, it is not known if the fish are congregating in the immediate vicinity of the aerator during periods of low DO.

Potential Management Alternatives

44. The reservoir ideally should be operated in a manner that will (a) prevent deposition of materials brought in by the spring runoff in the upper reaches of the reservoir and (b) flush a given summer's algal production from the system before the system fills for the winter. This may be infeasible if water requirements for the Wisconsin River preclude flushing during these periods. For this reason, other means may need to be sought to alleviate problems resulting from sediment deposition and algal production.

45. It may be necessary to remove sediment from portions of the main channel upstream by dredging. Deepening of the channel would provide the

added benefit of increased water volume relative to sediment surface area encountered during periods of drawdown. Chemically reduced sediments in areas of negligible turbulent mixing (e.g., near the dam) could perhaps be oxidized by additions of nitrate, which would elevate sediment redox potential and thus lessen the release of reductants into the overlying water column. Retention of iron would have the added advantage of lessening the phosphorus flux into the water column, thus possibly dampening phytoplankton production.

46. Structural modifications, including perhaps the construction of a sedimentation pool in the main upstream channel, may be required if the DO sag is determined to be caused primarily by sediment transport.

47. Alternate locations and alternate operational patterns for aerators may be required. Additional aeration in the upstream area where the delta deposits and the sag forms should promote consumption of allochthonous organics and prevent the sag from forming during the winter. In addition, it may be necessary to install additional aeration near the dam to prevent development there of a hypolimnetic oxygen demand. Over the long term it may be more effective to administer molecular oxygen from a liquid oxygen system, rather than aerating the reservoir to counteract the DO sag. Studies on the mechanisms (presently unclear) of sag development should provide the necessary information to evaluate these options.

48. It is most important to emphasize that the above "potential management alternatives" represent the outcome of speculative reasoning. Before any of these alternatives can be considered for implementation, additional studies should be conducted, based on the recommendations provided below.

Recommendations

49. The general recommendations of Shaw and Powers (undated) concerning the need to control agricultural sources of pollution to the system are valid. Shaw and Powers specified control of animal waste spreading during winter, particularly on the lower slopes of the watershed, and fencing of inflow streams at least 30 ft from stream channels. Better agricultural management practices that reduce loading of organic matter and phosphorus-laden sediments to the system, particularly during spring runoff, will eventually decrease oxygen depletion in the reservoir. However, it is not possible to predict how much time will be required for improvements in land use to rectify existing

water quality problems. Given the importance of internal nutrient loading in supporting phytoplankton production, the system may require an extensive period of time for improvements in land use to become effective. Shaw and Powers also recommended some specific reservoir management changes, including delayed summer drawdown to minimize internal phosphorus loading, delayed winter drawdown to at least mid-January, and an increase in minimum pool volume by 25 percent. These specific recommendations seem somewhat premature, given the extent of information deficiencies (see above) that must first be overcome.

50. More detailed information should be collected on contributions and fates of degradable organic matter entering the reservoir from different sources. Further, the rates of release and the chemical composition of materials released from the reservoir sediments should be determined. Information on sedimentation rate and sediment transport is also required, particularly in the area of the upstream delta formation. Profiles of sediment obtained by coring should be dated to provide information on long-term sediment accretion rates. The same cores should be analyzed chemically to relate changes in watershed activities (historical information) to chemical properties of sediment.

51. In addition, studies should be conducted to determine how much oxygen demand is occurring in the water column as compared to how much is being exerted from the bottom sediments. It is also necessary to establish the exact nature of the oxygen demand occurring in the winter months. Water from the sag as it moves downstream from areas of intensive hypolimnetic oxygen demand should be analyzed chemically during the progression of winter DO depletion. It is also necessary to obtain additional estimates of SOD to supplement those of Hammermeister. A fisheries study is also warranted during the winter to determine behavioral response of fish to the DO sag.

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Table 1

Interpretation of Winter Oxygen Depletion Data Supplied by WVIC

Year	Comments
1974	Typical example of drawdown and accompanying movement of DO sag downstream.
1975	Downstream movement of the DO sag between 16 Jan and 14 Feb associated with decreasing water levels.
1976	Increased flow on 18 Feb moved the DO sag down to the dam and added freshly oxygenated water into the system, explaining early removal of low DO water.
1977	Low inflows (less than 1 cfs) during continuous drawdown coupled with below-normal precipitation in 1976, which prevented refilling of reservoir in fall, gave the reservoir a water level nearly the same as the hypolimnetic demand zone. The entire reservoir was nearly anoxic, and a DO sag movement was not evident.
1978	Once water level fell below 1,135 ft on 2 Mar, DO sag was evident (seen on 10 and 17 Mar).
1979	Similar to 1978.
1980	Progressive movement of DO sag downstream beginning on 28 Jan above mile 18. WVIC notes this was an unusual year and did not have usual DO sag movement.
1981	DO sag developed on 28 Jan and 14 Feb in upper reaches of reservoir. Large fish kill occurred above mile 18.0. Thaw in February, combined with runoff, refilled reservoir and broke up the DO sag. Sag redeveloped below aerator on 11 Mar, presumably due to inability of aerator to consume high (>30 mg/ℓ) BOD levels. No fish kill in lower reservoir.
1982	DO sag movement similar to 1974, except that aerator at mile 6 broke up sag. However, the sag redeveloped downstream from the aerator. WVIC indicates that at times of high BODs, the aerator cannot supply oxygen needed to eliminate DO demand.
1983	High-water elevation for entire winter resulting from above-normal precipitation. Hypolimnetic demand was evident on 9 and 18 Feb. No sag observed, probably due to fact that water level never fell low enough to resuspend sediment.
1984	Again, had high water in winter. Areas of anoxic water were attributed to hypolimnetic demand.
1985	Similar to two preceding years. Sag apparent at higher water levels, possibly due to sediment accumulated in preceding years.
1986	Typical DO sag with minimal impact.
1987	Mild sag without much opportunity for sag development and movement prior to breakup in early to mid-March.
1988	Hypolimnetic demands with only mild development of DO sag.

Table 2

Seasonal BOD Characterization, Big Eau Pleine Reservoir and River, 1975-76

Season*	Site	N	BOD5	BOD20	Suspended Solids	Detritus
Summer	Top	11	4.5 ± 3.9	12.3 ± 11.6	30.4 ± 24.8	4.2 ± 3.2
	Bot	8	2.4 ± 1.1	6.6 ± 2.9	21.0 ± 5.4	11.5 ± 7.3
	Riv	1	1.2	2.7	4.8	1.3
Fall	Top	7	2.9 ± 1.0	8.0 ± 2.5	15.2 ± 5.2	5.3 ± 6.8
	Bot	4	2.2 ± 0.3	7.2 ± 1.4	12.1 ± 4.2	5.1 ± 0.5
	Riv	2	1.1 ± 0.1	3.1 ± 1.0	6.5 ± 5.7	1.7 ± 0.9
Winter	Top	8	2.1 ± 1.4	6.4 ± 4.7	9.0 ± 3.5	4.7 ± 0.6
	Bot	1	3.9	12.9	13.3	5.2
	Riv	6	3.4 ± 2.1	9.0 ± 5.4	31.2 ± 38.3	6.9 ± 5.0
Spring	Top	8	2.7 ± 1.0	8.1 ± 0.3	11.8 ± 6.4	5.0 ± 1.8
	Bot	1	2.7	8.1	19.7	6.4
	Riv	7	6.5 ± 4.3	16.6 ± 18.6	16.8 ± 18.6	6.2 ± 0.6

Note: Data taken from Swalby 1979 (Table 12, p 50). Values given are in milligrams per litre, at 5° and 20° C.

* Summer = June-September; fall = October and November; winter = December-March; spring = April and May.

Table 3

Estimated BOD Fluxes Into and Out of Big Eau Pleine Reservoir as Determined by the FLUX Program

Year	Flux In (C.V.)*	Flux Out (C.V.)	Difference (In - Out)
1973	1,204,313a** (0.030)	1,349,920b (0.056)	-145,607
1974	324,729a (0.058)	416,871b (0.050)	-92,142
1975	519,466a (0.057)	499,440a (0.047)	No significant difference
1976	695,447a (0.029)	841,086b (0.053)	-145,639
1977	224,367a (0.061)	102,185b (0.058)	+122,182
1978	874,172a (0.051)	949,489b (0.052)	-75,317
1979	1,037,116a (0.045)	1,446,718b (0.052)	-40,962
1980	1,400,076a (0.051)	1,475,535b (0.047)	-75,459
1981	434,376a (0.051)	680,995b (0.047)	-246,619
1982	948,758a (0.049)	1,292,009b (0.049)	-343,251
1983	942,640a (0.034)	961,835b (0.049)	-19,195
1984	677,802a (0.051)	1,097,137b (0.053)	-419,335
1985	726,548a (0.050)	1,249,576b (0.057)	-523,028
1986	1,311,401a (0.037)	1,812,635b (0.047)	-501,234
Mean	808,658	1,012,531	-192,739
Standard error	99,974	130,792	57,469

Note: Based on results of the FLUX program for estimating loadings and mass discharges. Values given are in kilograms per year.

* Coefficient of variation generated by the FLUX program.

** FLUX values into and out of the reservoir for a given year followed by the same letter are not significantly different; those followed by different letters in a given year are significantly different ($p < 0.05$).

Table 4

Estimated Total Phosphorus Fluxes Into and Out of Big Eau Pleine Reservoir as Determined by the FLUX Program

Year	Flux In (C.V.)*	Flux Out (C.V.)	Difference (In - Out)
1975	42,403a** (0.044)	21,003b (0.041)	+21,400
1976	41,831a (0.044)	38,826b (0.041)	+3,005
1977	19,713a (0.044)	4,471b (0.053)	+15,242
1978	61,813a (0.046)	41,619b (0.045)	+20,194
1979	72,146a (0.045)	61,530b (0.047)	+10,616
1980	94,900a (0.046)	62,631b (0.042)	+32,269
1981	34,316a (0.044)	29,673b (0.044)	+4,643
1982	68.296a (0.045)	53,724b (0.049)	+14,572
1983	60,442a (0.044)	40,168b (0.044)	+20,274
1984	55,211a (0.044)	47,250b (0.045)	+7,961
1985	56,997a (0.044)	57,266a (0.046)	No significant difference
1986	90,357a (0.044)	68,772b (0.047)	+21,585
Mean	58,235	43,914	+15,615
Standard error	6,595	5,672	2,745

Note: Based on results of the FLUX program for estimating loadings and mass discharges. Values given are in kilograms per year.

* Coefficient of variation generated by the FLUX program.

** FLUX values into and out of the reservoir for a given year followed by the same letter are not significantly different; those followed by different letters in a given year are significantly different ($p < 0.05$).

Table 5

Estimated Orthophosphate Phosphorus Fluxes Into and Out of Big Eau Pleine Reservoir as Determined by the FLUX Program

Year	Flux In (C.V.)*	Flux Out (C.V.)	Difference (In - Out)
1975	26,350a** (0.057)	6,693b (0.086)	+19,657
1976	28,980a (0.058)	12,237b (0.099)	+16,743
1977	14,544a (0.053)	1,397b (0.072)	+13,147
1978	41,446a (0.062)	12,174b (0.113)	+29,272
1979	46,030a (0.063)	15,174b (0.107)	+30,856
1980	57,893a (0.057)	11,562b (0.115)	+46,331
1981	24,170a (0.057)	9,709b (0.089)	+14,461
1982	44,606a (0.063)	14,574b (0.107)	+30,032
1983	39,889a (0.061)	11,774b (0.114)	+28,115
1984	35,648a (0.060)	16,150b (0.107)	+19,498
1985	36,526a (0.060)	16,374b (0.107)	+20,152
1986	55,213a	14,774b	+40,439
Mean	37,608	11,883	+25,725
Standard error	3,835	1,307	2,986

Note: Based on results of the FLUX program for estimating loadings and mass discharges. Values given are in kilograms per year.

* Coefficient of variation generated by the FLUX program.

** FLUX values into and out of the reservoir for a given year followed by the same letter are not significantly different; those followed by different letters in a given year are significantly different ($p < 0.05$).

Table 6

Seasonal Core Sediment Oxygen Demand* of the Big Eau Pleine Reservoir

Site	Date	Core SOD4	Core SOD12	Core SOD20
76-1	9-11-75	0.18	0.63	0.68
76-3	11-12-75	0.17	0.43	1.04
76-4	11-16-75	0.13	0.49	0.62
	Mean ± S.D.	0.18 ± 0.06	0.50 ± 0.13	0.83 ± 0.31
76-4	1-08-76	0.11	0.38	0.38
76-4	1-16-76	0.11	0.15	0.28
76-6	2-15-76	0.18	0.36	0.69
76-8	2-21-76	0.08	--	1.26
76-7	2-27-76	0.23	--	0.86
	Mean ± S.D.	0.14 ± 0.06	0.30 ± 0.13	0.69 ± 0.39
76-3	5-26-76	0.24	0.37	1.18
76-6	6-04-76	0.11	0.29	0.46
76-4	6-12-76	0.11	0.17	0.47
	Mean ± S.D.	0.15 ± 0.07	0.27 ± 0.10	0.70 ± 0.41
76-11	6-27-76	0.10	0.53	0.74
76-9	7-02-76	0.19	0.25	0.33
76-8	7-14-76	0.21	0.38	0.62
76-5	7-29-76	0.16	0.38	0.58
76-10	9-20-76	0.17	0.29	0.52
	Mean ± S.D.	0.17 ± 0.04	0.37 ± 0.11	0.56 ± 0.15
	Grand mean ± S.D.	0.15 ± 0.05	0.36 ± 0.13	0.67 ± 0.29
	N	16	14	16

* Values given are in grams oxygen per square metre per day, at 4°, 12°, and 20° C.

Table 7

Results of Analyses on Sediment Cores Taken from Upstream and Downstream Sites, Big Eau Pleine Reservoir

Constituent	Upstream Site	Downstream Site
Interstitial Water Contents		
K, mg/ℓ	7.54	8.00
Ca, mg/ℓ	50.0	34.1
Fe, mg/ℓ	24.3	24.2
Mn, mg/ℓ	3.71	4.10
NH_4-N, mg/ℓ	5.72	5.29
SRP, mg/ℓ	0.740	0.132
Mg, mg/ℓ	18.6	12.8
Na, mg/ℓ	8.2	5.6
Dissolved inorganic carbon, mg/ℓ	48.2	43.1
Dissolved organic carbon, mg/ℓ	37.6	34.7
Bulk Sediment Properties		
Moisture, %	32.8	48.0
Bulk density, g/ml	1.28	0.875
Organic content, %	3.83	5.28
Texture		
Sand, %	49	57
Silt, %	37	30
Clay, %	14	13